Uncertainties and Interdisciplinary Transfers Through the End-to-End System (UNITES): Capturing Uncertainty in the Common Tactical Environmental Picture

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LONG-TERM GOALS

UNITES is a unique, interdisciplinary team with expertise spanning the environment (physical oceanography and bottom geology), ocean acoustics (propagation, ambient noise, reverberation and signal processing), and tactical sonar systems. The overall goals of the research are to enhance the understanding of the uncertainty in the ocean environment (including the sea bottom), characterize its impact on sonar system performance, and provide the Navy with guidance for understanding sonar system performance in the littoral.

OBJECTIVES

Specific objectives of the team effort are to:

1) Develop generic methods for efficiently and simply characterizing, parameterizing, and prioritizing sonar system variabilities and uncertainties arising from regional scales and processes.
2) Construct, calibrate and evaluate uncertainty and variability models, for the sonar systems and its components, to address forward and backward transfer of uncertainties.
3) Transfer uncertainties from the acoustic environment to the sonar and its signal processing, in order to effectively characterize and understand sonar performance and predictions.

APPROACH

Our technical approach is based on utilizing environmental probability density functions (PDF) to provide a description of sonar performance. The PDFs will be determined for appropriate spatial and temporal scales as dictated by the systems under consideration. In particular, these PDFs will be determined for the following: meso- and sub-mesoscale fronts and eddies, tides, internal tides, waves and solitons, interference variability (ambient noise and reverberation) and spatially variable bottoms. Abbot is one of two co-leaders of the team and is working in close collaboration with team members.

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14. ABSTRACT
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WORK COMPLETED

We attended the ONR Kick-Off Meeting held at University of Washington, Applied Research Laboratory in June 27 and 28, 2001 and presented an overview of the UNITES Team Approach. The presentation, entitled "Uncertainties and Interdisciplinary Transfers Through the End-to-End System (UNITES): The UNITES Team Approach" was presented by Allan Robinson (Harvard University) and Phil Abbot. A UNITES Team kick-off meeting was held at Harvard University on May 30, 2001 to prepare for this presentation.

We have been working in close collaboration with the WHOI Principal Investigators (Lynch, Duda, and Gawarkiewicz) in developing specific rules-of-thumb to help improve system performance predictions, using data sets from PRIMIER, SHAREMs and ASIAEX. This has involved several meetings at WHOI and OASIS, and culminated in a presentation to Navy fleet personnel at WHOI on September 6, 2001. The presentation by Jim Lynch (WHOI) and Abbot entitled "Environmental Uncertainty – Tactical Applications" resulted in suggestions on transitioning UNITES uncertainty insight to the fleet.

We have commenced analyses to address the nature of uncertainty for East China Sea transmission loss measurements. Measurement system uncertainty, environmental uncertainty from internal tides, spatially varying bottom geoacoustics and ordinary range-cycle propagation fluctuations have been characterized and appropriate environmental probability density functions have been developed. Although preliminary, the results suggest that the uncertainty in the spatially varying bottom is the dominant mechanism of the acoustic transmission loss in this particular bottom-limited environment.

RESULTS

An illustrative example using environmental probability density functions for performance predictions is shown in Figures 1 and 2. In Figure 1, the environmental probability density function, developed for a system operating in a downward-refracting, shallow water environment is shown. A histogram based on the difference between the measured and modeled signal-to-interference ration (SIR) for the system is plotted, then fit with a distribution function (chi squares fit in the example). The resulting SIRE-PDF describes the distribution of the predictive capability of the present model (for a given location and time period) with respect to the measurements (actual performance) and therefore represents the uncertainty in our ability to model the actual performance of the system. Thus, this accounts for the inherent variability of the environment not contained in the current model, and is a useful probabilistic description of the environment's intrinsic variability.

The PDF shown in the figure has a mean and standard deviation of 0 dB and 5 dB, respectively. The thrust of the present effort is to understand the physics that determines the distribution. On-going preliminary analyses suggest that the 5 dB standard deviation is comprised of the following terms: 2 dB each from outgoing and incoming TL, 3 dB from the reverberation (set by spatially varying bottom scattering strength), 2 dB each from the outgoing and incoming (bottom to receiver) TL. These terms are considered statistically independent and thus the total standard deviation is the square root of the sum of the squares of the individual components, = 5 dB.

Ultimately, one of the primary efforts of the present research is to determine the corresponding PDFs resulting from the environmental processes and to evaluate their effect on performance.

Figure 2 also shows an illustrative example of using the SIRE-PDF with predictions of the sonar system SIR to determine the predictive probability of detection (PPD) for the system of interest. The SIRE-PDFs are shown at range increments of 5 km and the range of the integrals (as set by the threshold level) are shown in red. At the bottom of the plot is the resulting PPD, which is close to unity at close-in ranges and slowly decrease as the range increases. The PPD shown is a prediction of the system performance versus range, and the uncertainties in the model due to environmental variability and other effects are accounted for in this function. The PPD may provide the system operator with a probabilistic representation of the system performance as a function of range. This distribution of ranges is based on the best modeling capability coupled with a realistic statistical description of the uncertainties.

IMPACT/APPLICATIONS

The primary application is to assist the sonar "prediction community" by providing a probabilistic representation of sonar system performance. The present approach provides a systematic method to incorporate uncertainties due to the environment and to transfer the effects of these uncertainties, in the end-to-end problem through the sonar systems under consideration. The operator can thus use this information to operate the system more effectively and make more informed decisions on search, risk, expenditure of assets (weapons) and assumptions of covertness.

TRANSITIONS

Rules-of-thumb, lessons learned, technical implications for effective environmental sampling strategies for the fleet and other tactical insights will be presented to appropriate fleet personnel. We expect to transition specific uncertainty ideas (rules-of-thumb, sampling strategies) through the Advanced Processor Build (APB) program.

The Navy has formed a working group entitled Sensor Optimization Working Group (a subset of the Sonar Development Working Group) to improve sonar system performance predictions in the littoral. We anticipate presenting the uncertainty derived rules-of-thumb and the concept for environmental probability density functions to this group within the next few months. We anticipate briefing other appropriate fleet personnel this fall and winter.

Also, the Multi-Static Active ASW System is currently being transitioned to the Navy through the Advanced Systems Technology Office. Recognition of the environmental uncertainty on acoustic propagation is important for the development of fleet rules-of-thumb and tactical documents. Present uncertainty analyses are being used by ASTO in the development of a tactical memo for system operation in the ECS environment, including rules-of-thumb for effective source and receiver placements.

RELATED PROJECTS

1 – The Multi-Static Active ASW System is currently being transitioned to the Navy through the Advanced Systems Technology Office (ASTO). The predictive probability of detection curves derived from the UNITES Team are being utilized by ASTO in this program.

PUBLICATIONS

A draft article entitled, "Effects of East China Sea Shallow Water Environment on Acoustic Propagation, Including Environmental Uncertainty" is in progress and will be submitted to the IEEE Journal of Oceanic Engineering this winter.

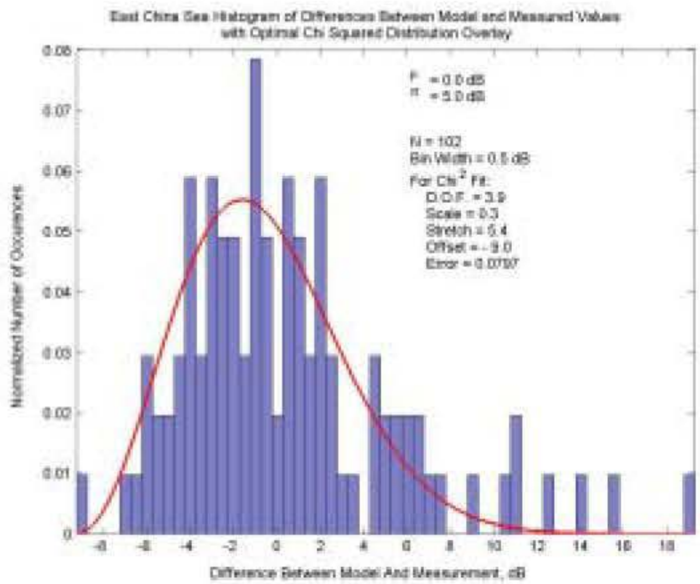

Figure 1: Signal-to-Interference Ratio Environmentally-induced Probability Density Function (SIRE-PDF), for tactical system operating in shallow water, downward refracting environment. This function is a useful probabilistic description of the environment's intrinsic variability.

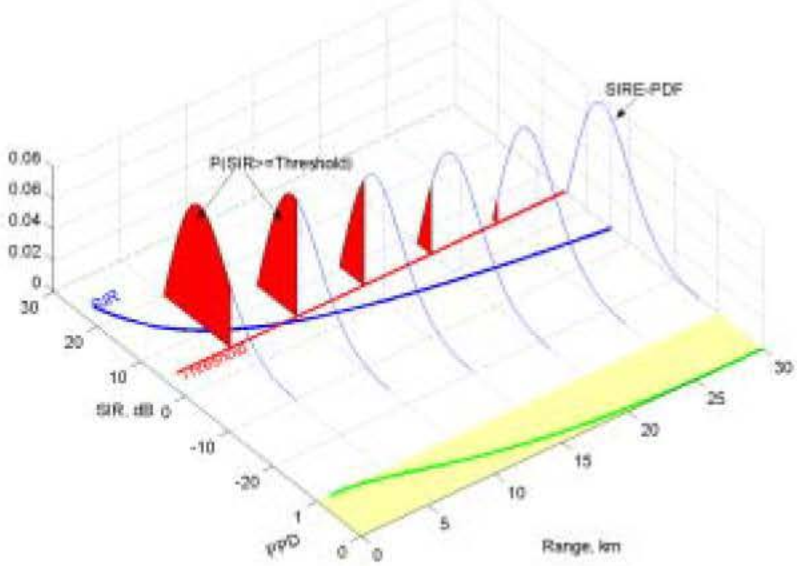

Figure 2: Illustrative example of using the SIRE-PDF with an estimate of sonar system performance (SIR) to determine the system's Predictive Probability of Detection (PPD) versus range, a probabilistic representation of the system performance.